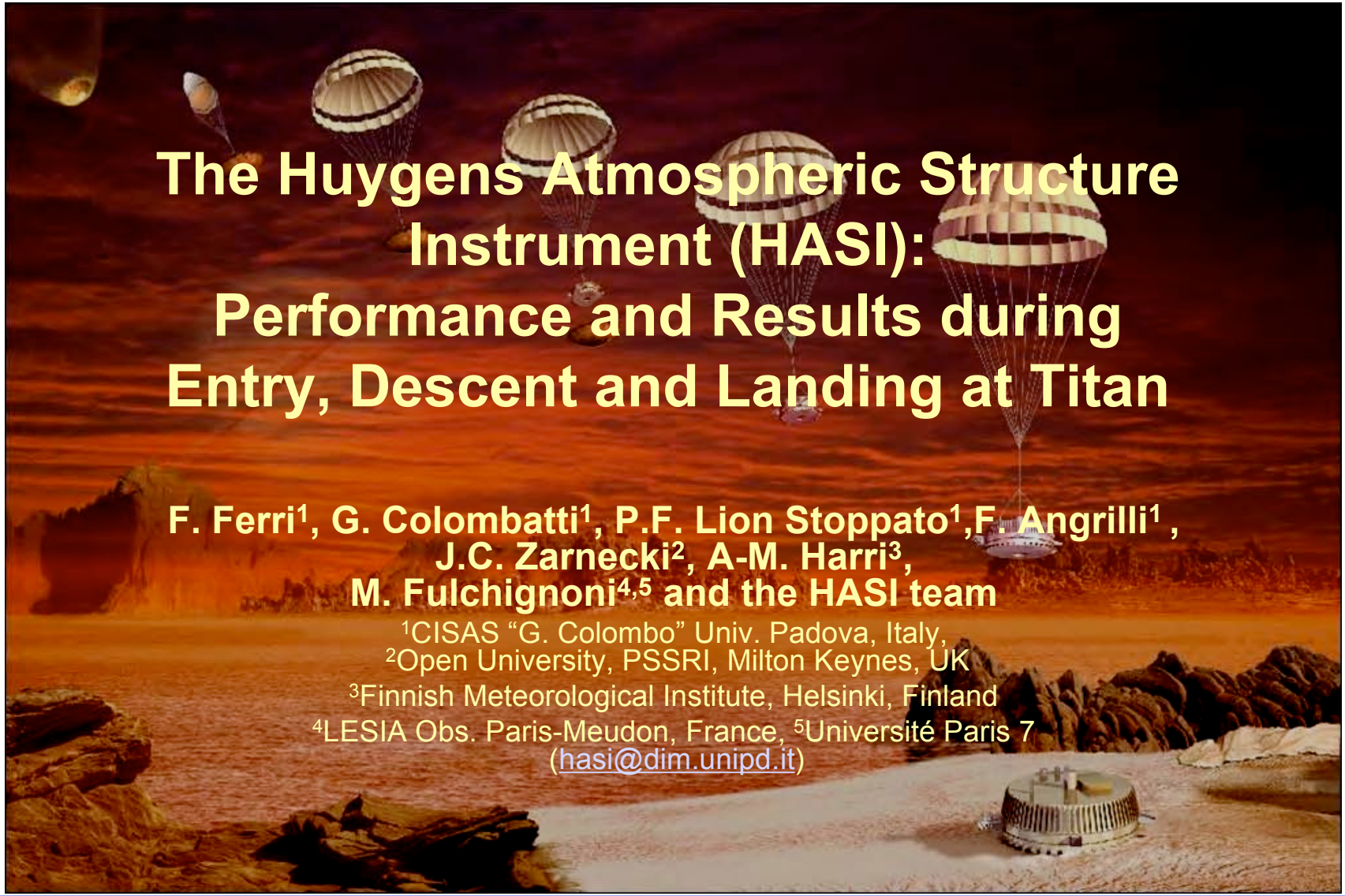
Abstract

- **THE HUYGENS ATMOSPHERIC STRUCTURE INSTRUMENT (HASI): PERFORMANCE AND RESULTS DURING ENTRY, DESCENT AND LANDING AT TITAN.**
- F. Ferri, G. Colombatti, P.F. Lion Stoppato, F. Angrilli
CISAS "G.Colombo" - Università di Padova, Via Venezia, 1 35131 Padova – Italy hasi@dim.unipd.it
- J.C. Zarnecki, *PSSRI – Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom*
- A.M. Harri, *FMI (Finnish Meteorological Institute), Helsinki, Finland*
- M. Fulchignoni, *LESIA, Observatoire de Paris-Meudon, 5 place Jules Janssen, 92190 Meudon, France*
- and the HASI team
- During the Huygens probe mission at Titan on January 14th, 2005 the Huygens Atmospheric Structure Instrument (HASI) operated nominally during the entry, descent and surface phases.
- The HASI ACC, the most accurate accelerometer ever flown in a planetary entry probe, started to acquire data before the atmospheric entry (at ~2800 km) allowing detecting Probe coning motion.
- The atmospheric profile along the Huygens probe trajectory during entry phase have been retrieved from the accelerometers data, while below 160 km, during the parachuted descent, direct pressure and temperature measurements have been performed by sensors having access to the unperturbed Probe boundary layer.
- The impact signature has been recorded by the triaxial accelerometers and meteorological and electrical conditions at ground have been continued to be monitored for about a half hour after impact.
- Monitoring axial and normal accelerations and performing direct pressure and temperature measurements during the descent, HASI provided a unique contribution to the reconstruction of the Probe trajectory and attitude.
- An overview of the HASI performance and results will be presented and discussed.
- **3rd International Planetary Probe Workshop**
-
- **June 27 – July 1, 2005,**
- **EDEN Beach Hotel-Club,**
- **Anavyssos, Attiki, GREECE**

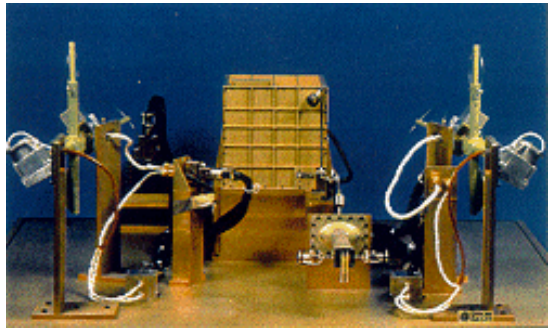


The Huygens Atmospheric Structure Instrument (HASI): Performance and Results during Entry, Descent and Landing at Titan

F. Ferri[1], G. Colombatti[1], P.F. Lion Stoppato[1],F. Angrilli[1] , J.C. Zarnecki[2], A-M. Harri[3], M. Fulchignoni[4,5] and the HASI team

[1]CISAS "G. Colombo" Univ. Padova, Italy,
[2]Open University, PSSRI, Milton Keynes, UK
[3]Finnish Meteorological Institute, Helsinki, Finland
[4]LESIA Obs. Paris-Meudon, France, [5]Université Paris 7
(hasi@dim.unipd.it)

Huygens Atmospheric Structure Instrument (HASI)

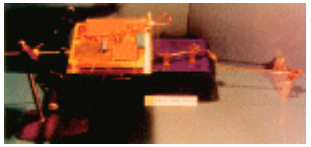


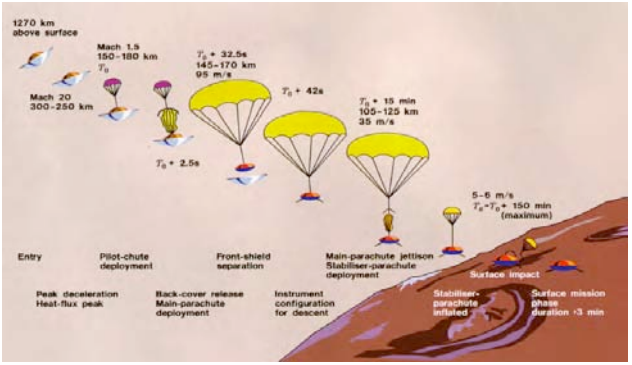
Principal Investigator: M. Fulchignoni

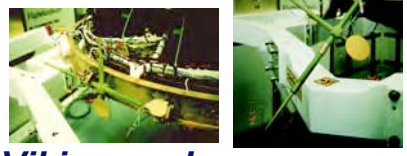
- **Study of Titan's atmosphere and surface**

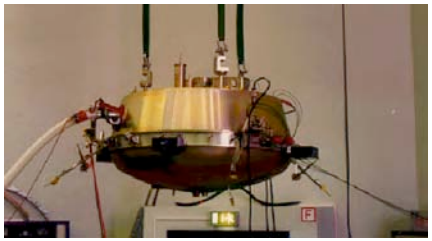
by measuring

- **acceleration** (ACC)
- **pressure** (PPI)
- **temperature** (TEM)
- **electrical properties** (PWA, RAU)
- ***Heritage: Pioneer Venus, Venera, Galileo, and Viking probes***

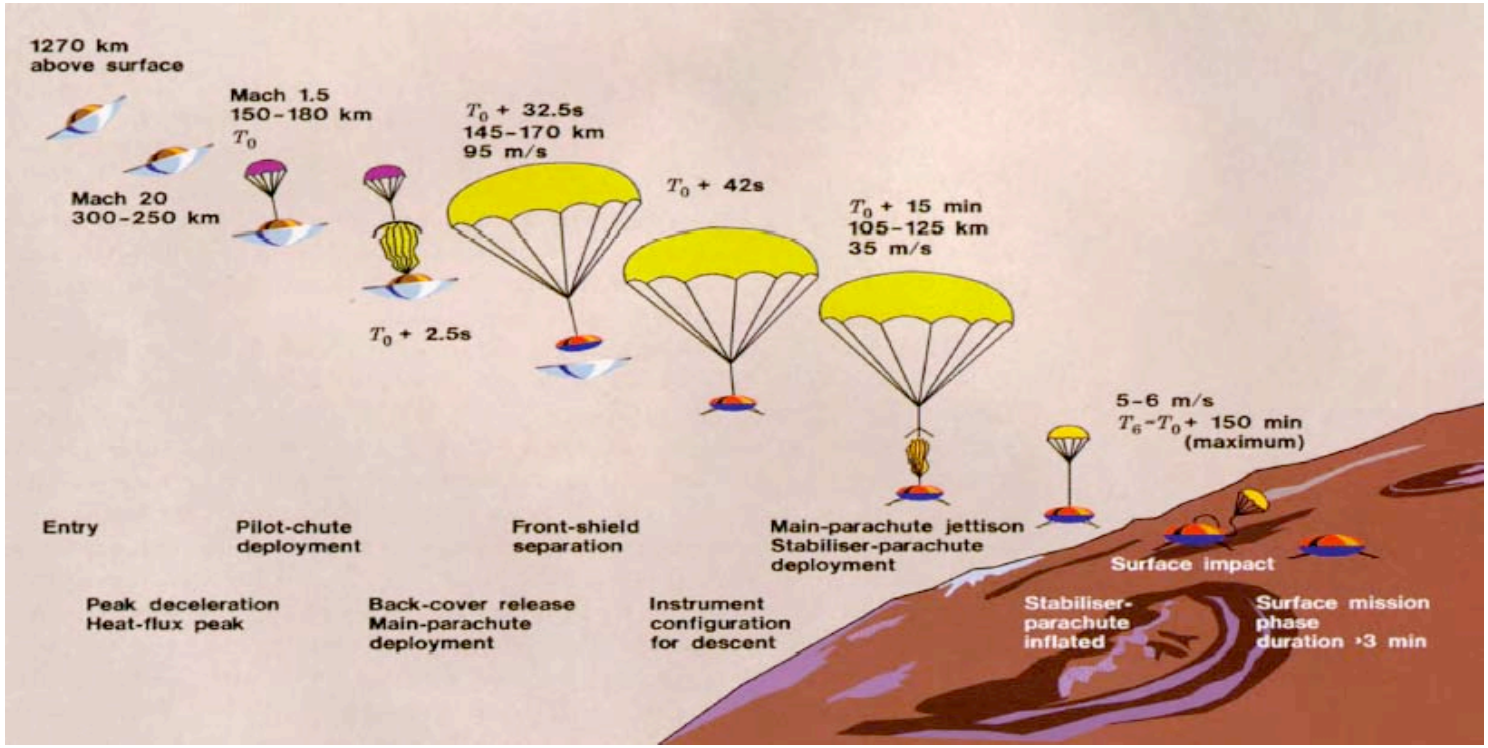








HASI operations

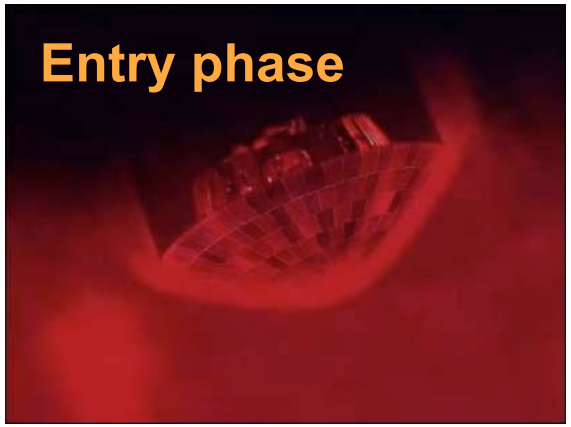


- HASI was the first instrument to be operating (~ 20 min before T0)
- ACC measurements started at ~2800 km
- After parachute deployment, direct p & T, and electrical measurements
- HASI data represent the unique contribute to the Huygens probe trajectory and attitude reconstruction

HASI
Huygens Atmospheric Structure Instrument

HASI measurements at Titan

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"



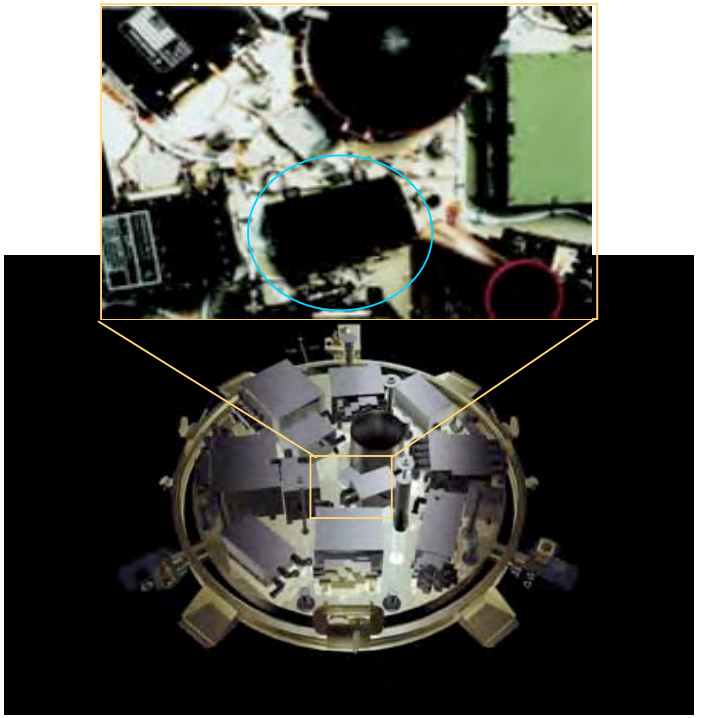
- *From ~ 1500 to 160 km*
  atmospheric physical properties from **accelerometer data**

- *From ~ 160km down to surface descent under parachute*

  T & **p** directly measured by sensors having access to the unperturbed field outside the probe boundary layer.
  PWA booms deployed: direct measurements of **electrical properties** and **acoustic recording**

HASI ACC package

- 4 accelerometers at CoG:
  - 3 piezoresistive sensors (X,Y,Z)
  - 1 **ACC X-Servo accelerometer**
- Type: Sundstrand QA2000
- acceleration measurement by sensing the current required to bring back a seismic mass to its null position.



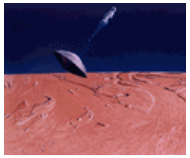
Sensor	*Measurement*	*Range*		*Resolution*		*sampling*
ACC X-Servo (Axial acceleration)	*high resolution*	*High Gain* ±2 mg	*Low Gain* ±20 mg	*High Gain* 1 µg	*Low Gain* 10 µg	100 Hz (12 bits)
	low resolution	*High Gain* ±1.85 g	*Low Gain* ±18.5 g	*High Gain* 0.9 mg	*Low Gain* 9 mg	

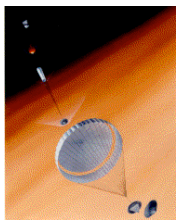
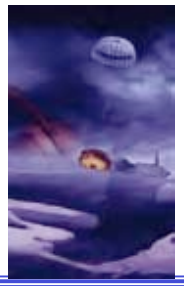
Main objective: to measure the **Huygens probe's acceleration** and thus to derive **Titan's atmospheric density profile**.

HASI
Huygens Atmospheric Structure Instrument

Comparison with previous missions

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"



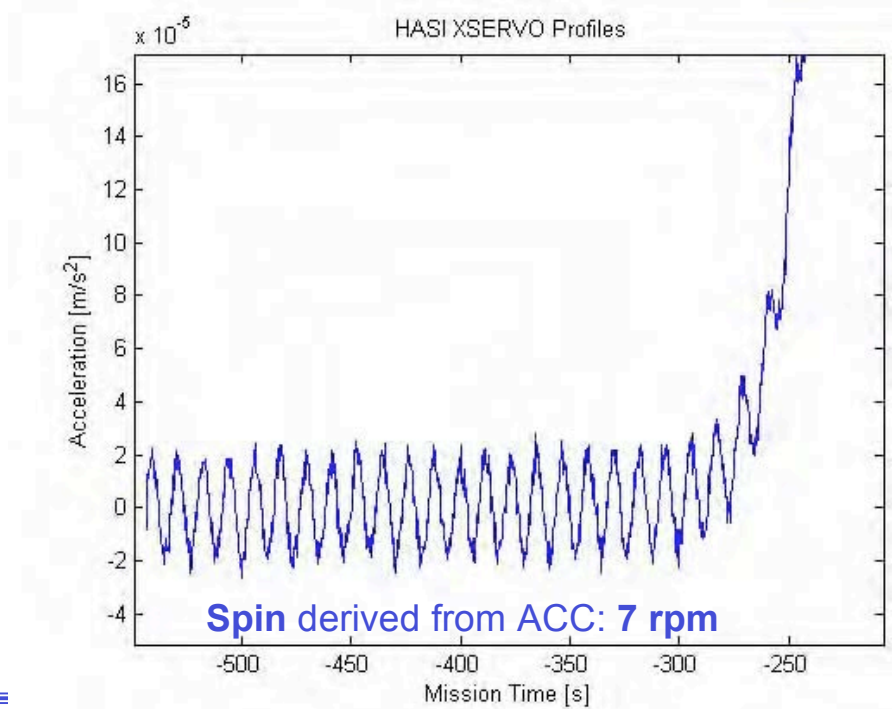
Missions	*Uncertainty in High Sensitivity Range (µg)*
Viking 1 & 2	±6.1
Pioneer Venus	Most sensitive channels (100 µg & 10 µg) failed
Galileo	4000
Mars Pathfinder	~ 4 (noise)
Mars Exploration Rover (MER)	35 (noise)
Huygens HASI ACC	Noise: 0.3 offset: ≤ 4 accuracy: 1% full scale

Ref. Zarnecki et al. IPPWS#2 Lisboa Sept. 2004

HASI operational report

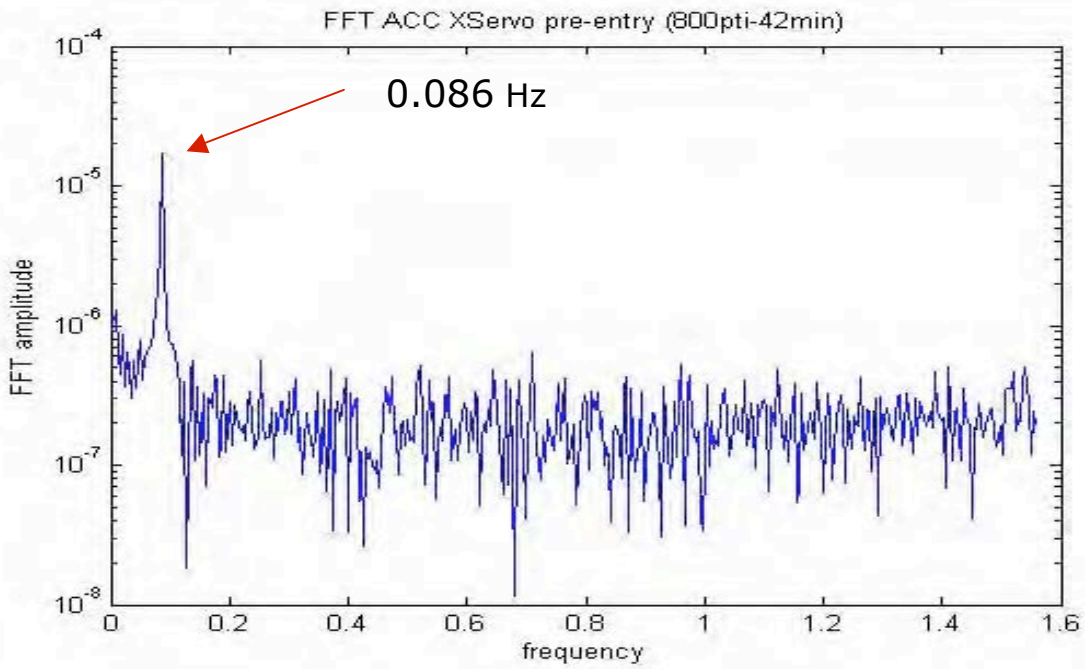
- HASI switched on before atmospheric entry
- HASI ACC measurements starting from ~ 2800 km
- Most accurate accelerometer ever flown in a planetary probe
- Sensitivity threshold allows to measure Probe coning motion.

Channels readouts:
Xservo @ 3.125 Hz
3 axis ACC PZR @ 1.613Hz

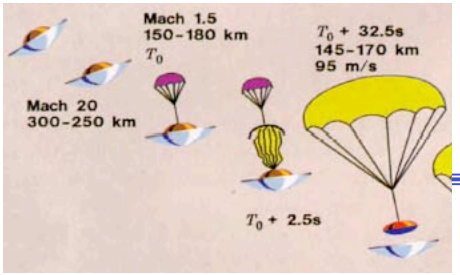


ACC provided by UKC-Open University
CoIs: J.C. Zarnecki, J.A.M. Mc Donnell

Spin in pre-entry



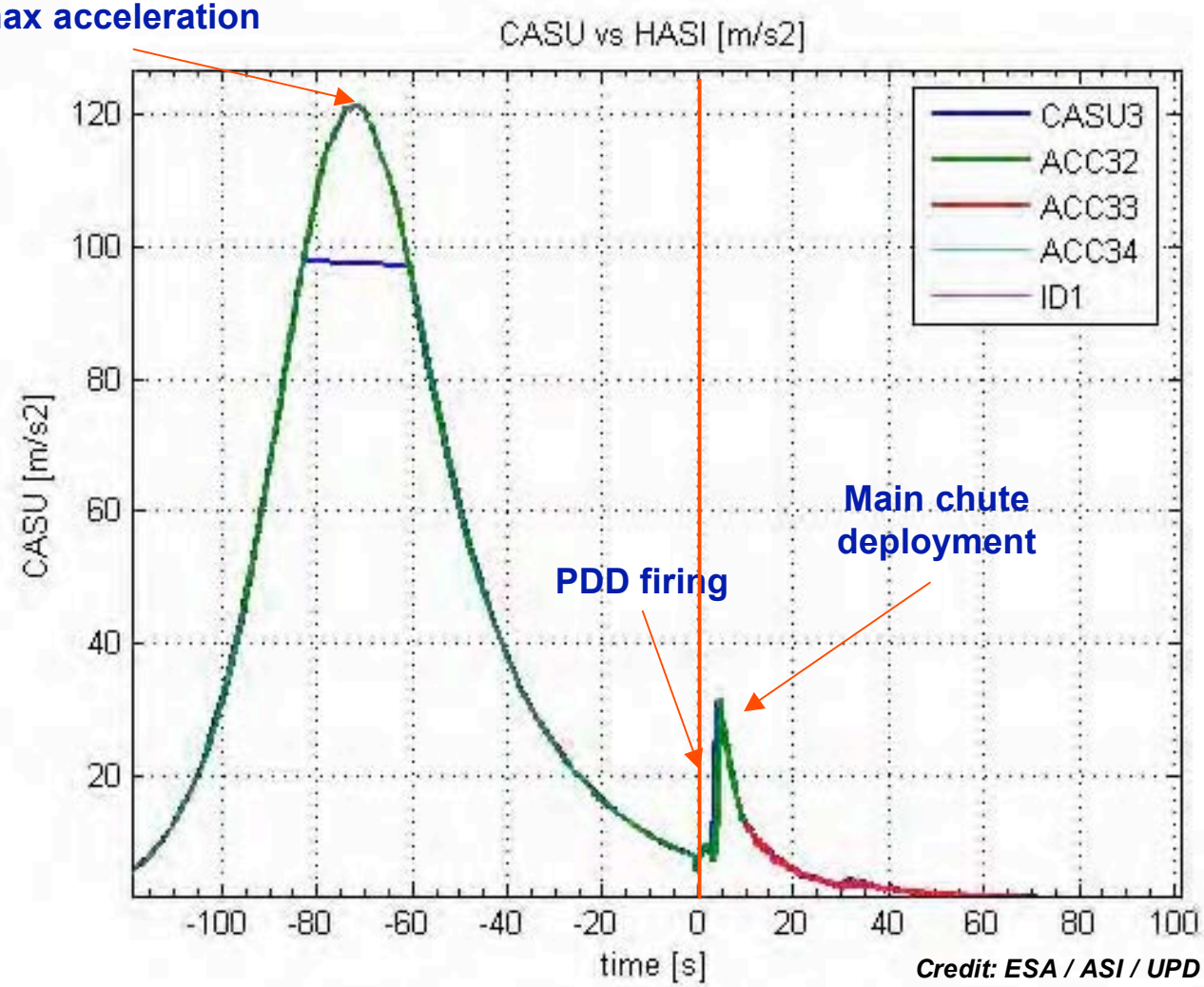
$$\omega_X = \omega_p \frac{1}{\sqrt{\frac{abs((I_{ZZ} - I_{XX})(I_{XX} - I_{YY}))}{I_{ZZ} I_{YY}}}} = \sim 7 \text{ rpm}$$



HASI ACC during entry

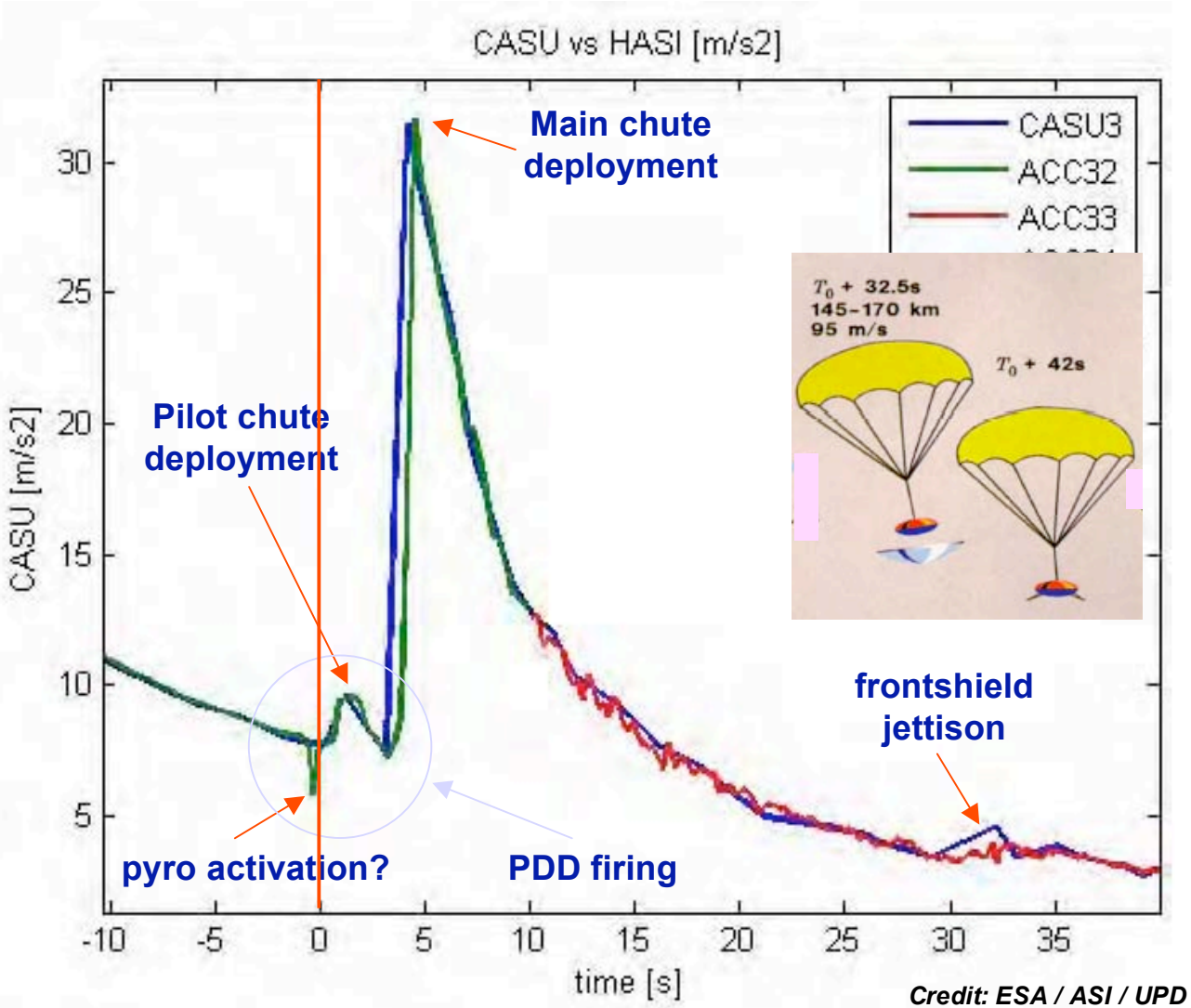
CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

max acceleration



Credit: ESA / ASI / UPD / OU /

HASI ACC: descent beginning



Credit: ESA / ASI / UPD / OU /

HASI atmospheric structure

From **acceleration measurements**

↓

density profile

from the top of atmosphere (1500 km)
to parachute deployment at approx 160 km

probe mass (kg)

acceleration component
in the direction of descent (ms^{-2})

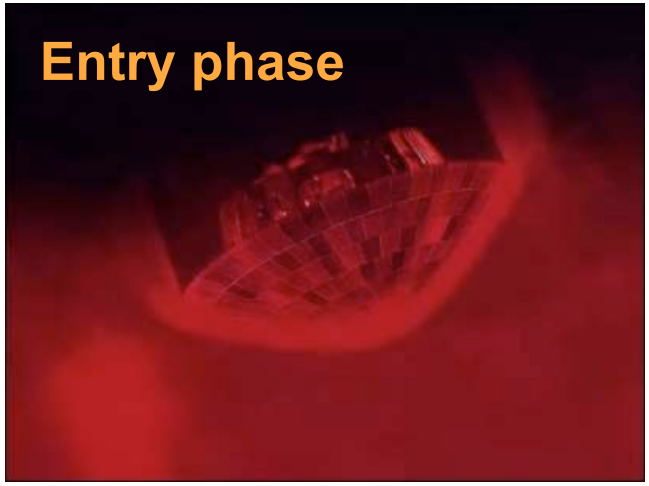
$$\rho = -\frac{2ma}{v^2 C_d A}$$

velocity relative to atmosphere
in the direction of descent (ms^{-1})

aerodynamic drag coefficient

probe cross-sectional area (m^2)

Upper atmosphere



Hydrostatic equilibrium

$$dp=-g\rho dz \qquad (1)$$

Equation of state of perfect gas

$$\rho= \mu p/RT \qquad (2)$$

$$\boldsymbol{\rho(z)}=-2(m/C_DA)(a/V_r^2)$$

$\mathbf{V_r}$ and **z** from measured acceleration & initial conditions

Indirect T & p measurements

Hydrostatic equilibrium + perfect gas

$$dp=-g\rho dz=-(pg\mu/RT)dz$$

gravity

$$g(z)=g_0(R_{Titan}/z)^2$$

p(z) integrating (1) with measured **ρ(z)** (initial condition to be assumed)

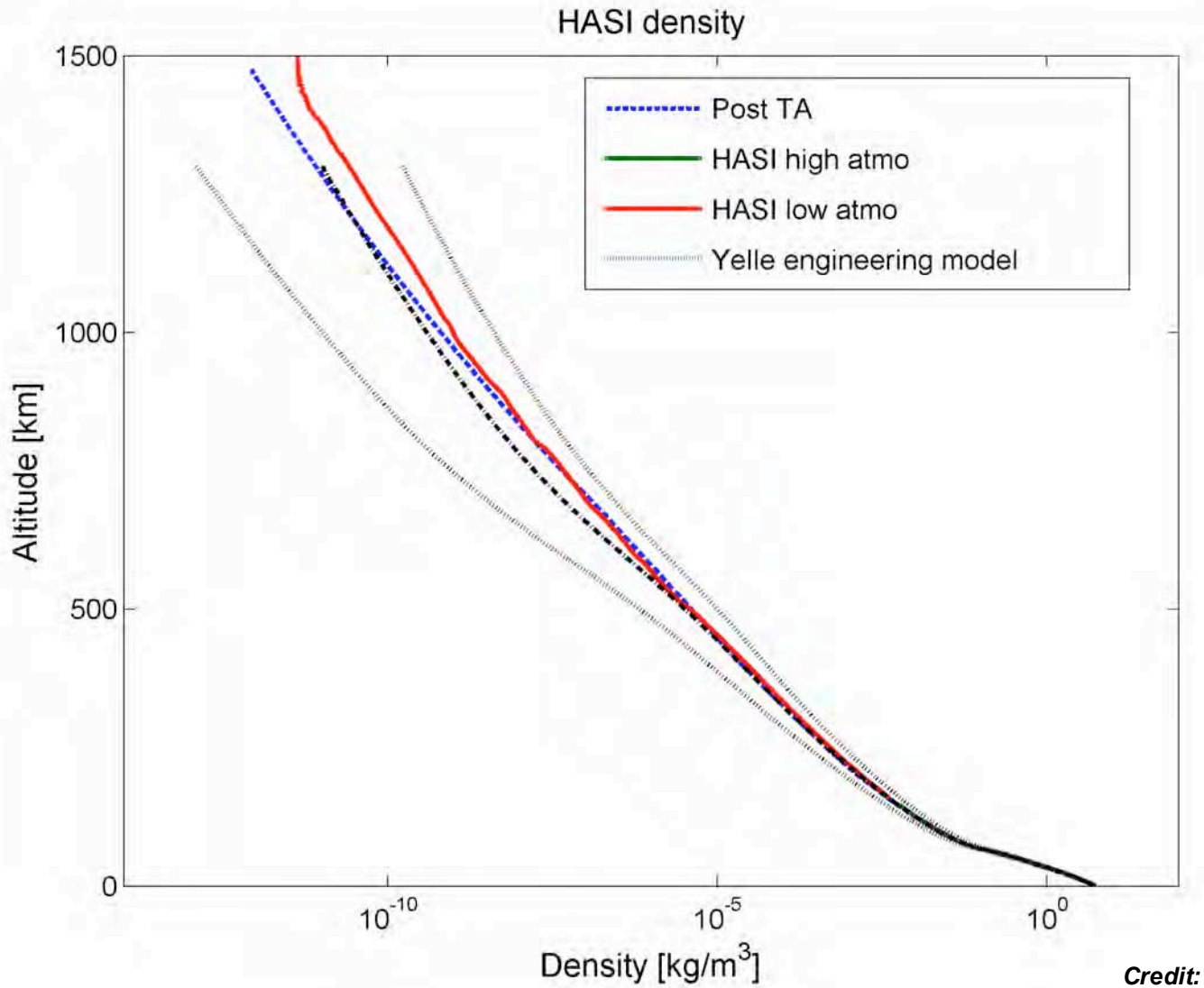
T(z) from (2) $T= \mu p/\rho R$

Density, pressure and temperature profiles

HASI
Huygens Atmospheric Structure Instrument

HASI density profile

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"



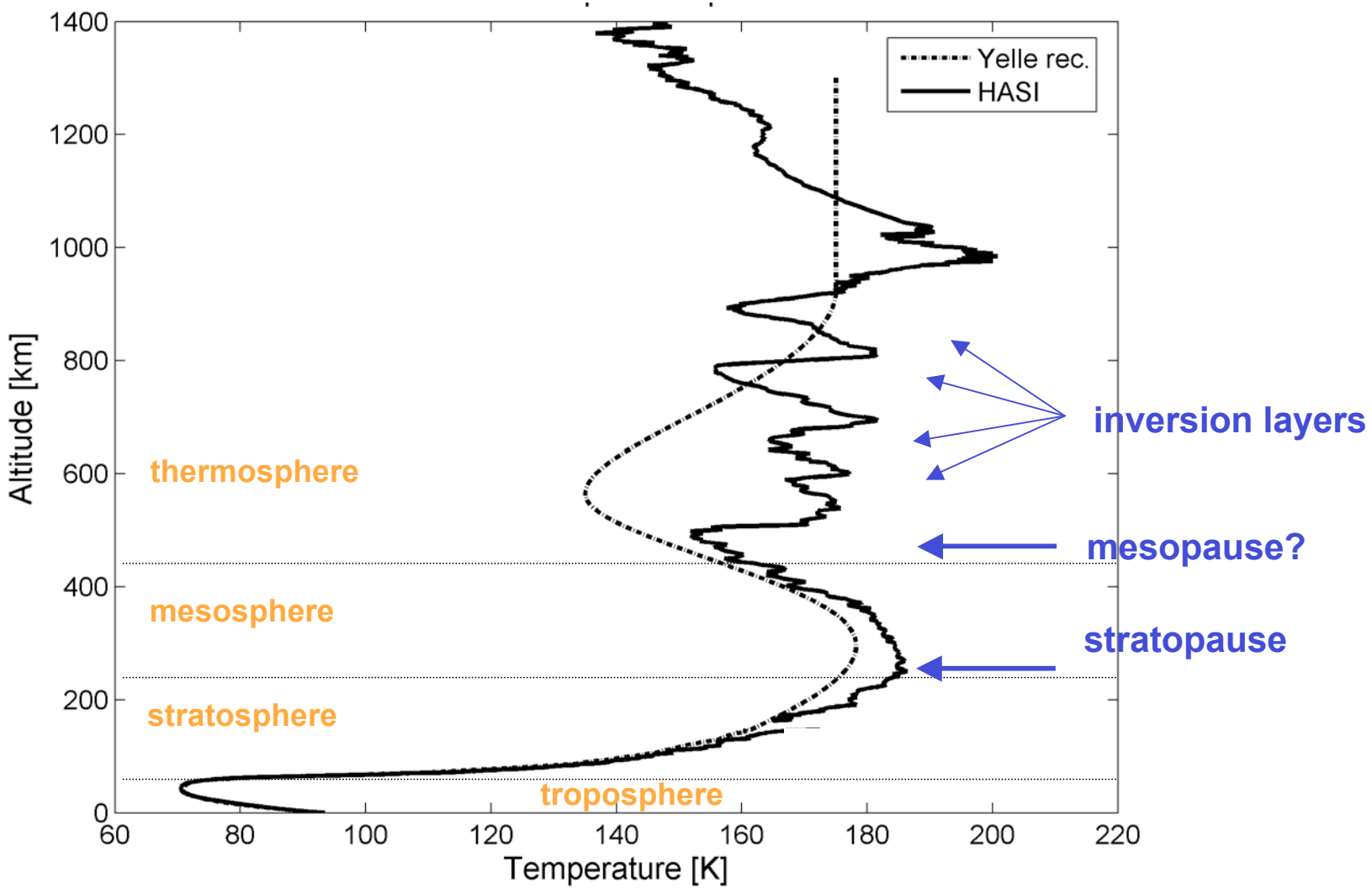
Credit: ESA / ASI / UPD / OU /

Upper atmosphere parameters: uncertainty

$$\rho = -\frac{2ma}{v^2 C_d A} \rightarrow \Delta\rho/\rho \sim 10\%$$

Parameter	value	comment	Uncertainty %
M	Probe mass	Measured & estimated (ablation)	~ 1%
v	Velocity relative to atmosphere	To be derived from time integration of acceleration	~ 2 %
Initial conditions	*Entry state* *1 sigma altitude* *FPA*	*Provided by Cassini NAV*	*~ 30 km* *± 0.3*
C_d	Aerodymanical drag coefficient	From Huygens aerodynamical data base	5%
A	Probe cross-sectional area	Measured & estimated (ablation)	0.1%
a	Probe acceleration	measured	@1300 km ~ 5% @1200 km ~ 1%

HASI temperature profile



Credit: ESA / ASI / UPD / OU / FMI

HASI
Huygens Atmospheric Structure Instrument

HASI during DESCENT phase

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

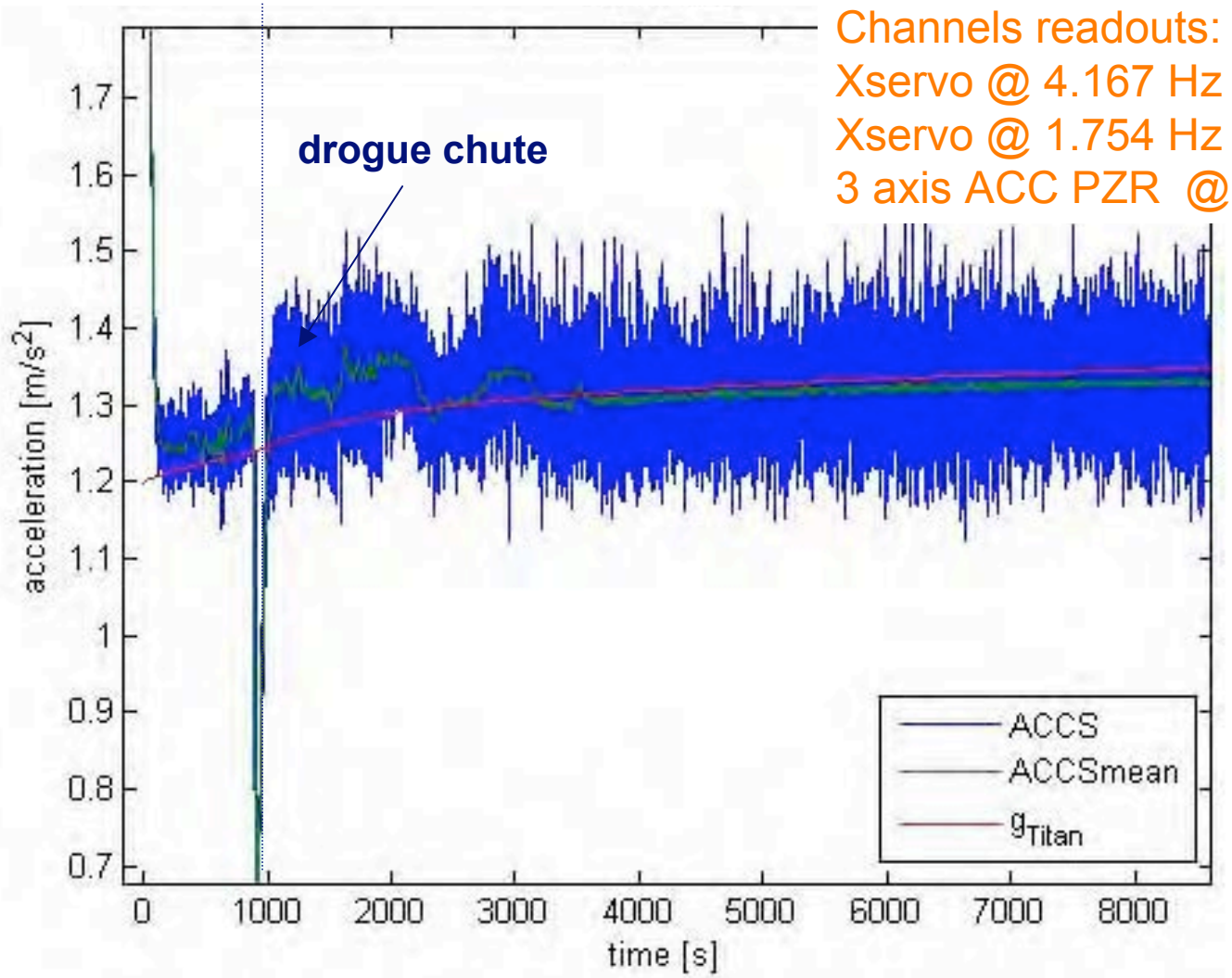
Starting from ~162 km, descent under parachute

T & **p** directly measured by sensors having access to the unperturbed field outside the probe boundary layer.

PWA booms deployed: direct measurements of electrical properties and acoustic recording

Huygens radar altimeter :
HASI-PWA radar return signal elaboration from ~40 km (lock achieved at ~40 km)

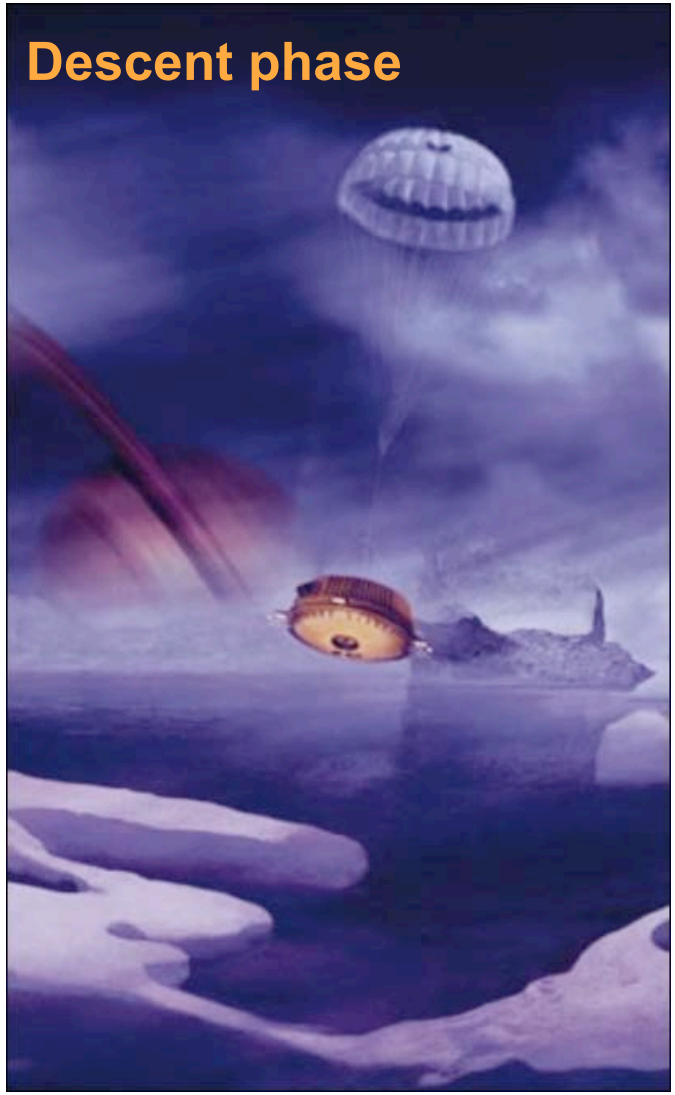
ACC XServo during descent



Channels readouts:
Xservo @ 4.167 Hz (til T0+32 min)
Xservo @ 1.754 Hz
3 axis ACC PZR @ 1.613Hz

For attitude reconstruction ref. to Poster by Bettanini et al.

Lower atmosphere: atmospheric structure



Starting from 162 km, descent under parachute

From measured **p** & **T**, assuming hydrostatic equilibrium

$$dp=-g\rho dz=-(pg/RT)dz \qquad (1)$$

Altitudes & velocities as fz of time:

z(t) integrating (1)

$$\mathbf{v(t)}=dz/dt=-(RT/\mu gp)(dp/dt)$$

Dry adiabatic atmosphere

ρ(z) from equation of state

$p=\zeta\rho RT$ ζ compressibility factor

μ(p) & R(p) μ from GCMS

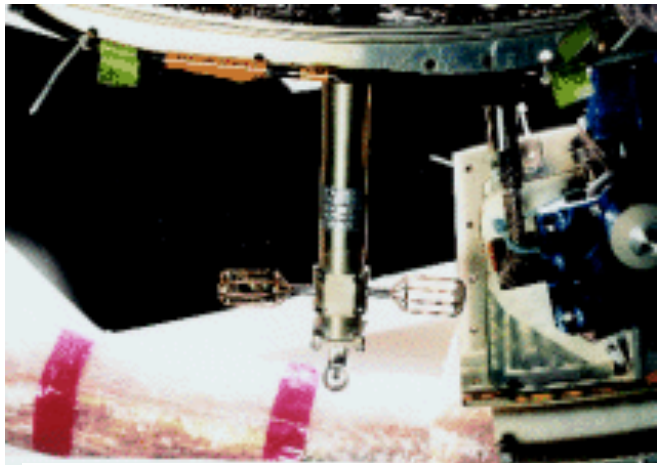
Lapse rate $\mathbf{dT/dz}=-(g/R)(d\mathit{ln}T/d\mathit{ln}p)$

HASI
Huygens Atmospheric Structure Instrument

HASI TEMperature sensors

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

- Two redundant dual element platinum resistance thermometers (**TEM**).
- The primary sensor (FINE) directly exposed to the air flow
- The secondary sensor (COARSE) is designed as spare unit in case of damage of the primary sensor.
- Temperature measurement by monitoring resistance



range	Resolution	Accuracy
Low T (60-110K)	0.02K	0.25K
High T (100-330K)	0.06K	1K

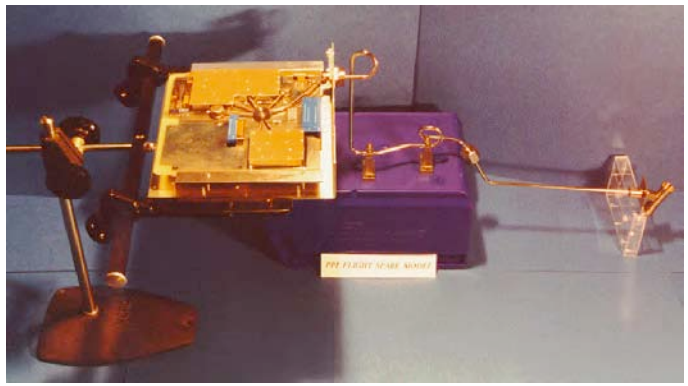
Main objective: to measure **Titan's atmospheric temperature profile**.

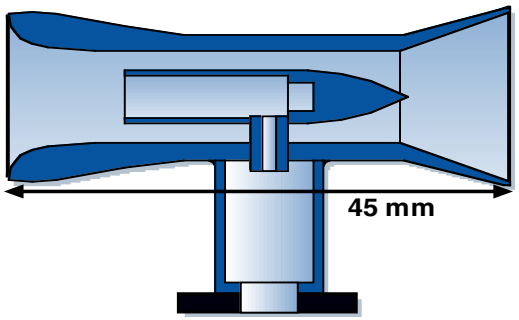
HASI
Huygens Atmospheric Structure Instrument

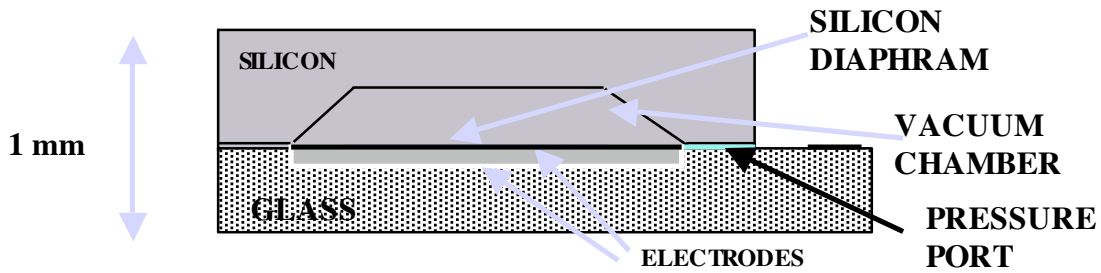
HASI Pressure Profile Instrument

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

- The atmospheric flow is conveyed through a **Kiel probe** inside the DPU where transducers and electronics are located.
- **PPI** transducers are silicon capacitive absolute pressure sensors (*Vaisala* **Barocap**).







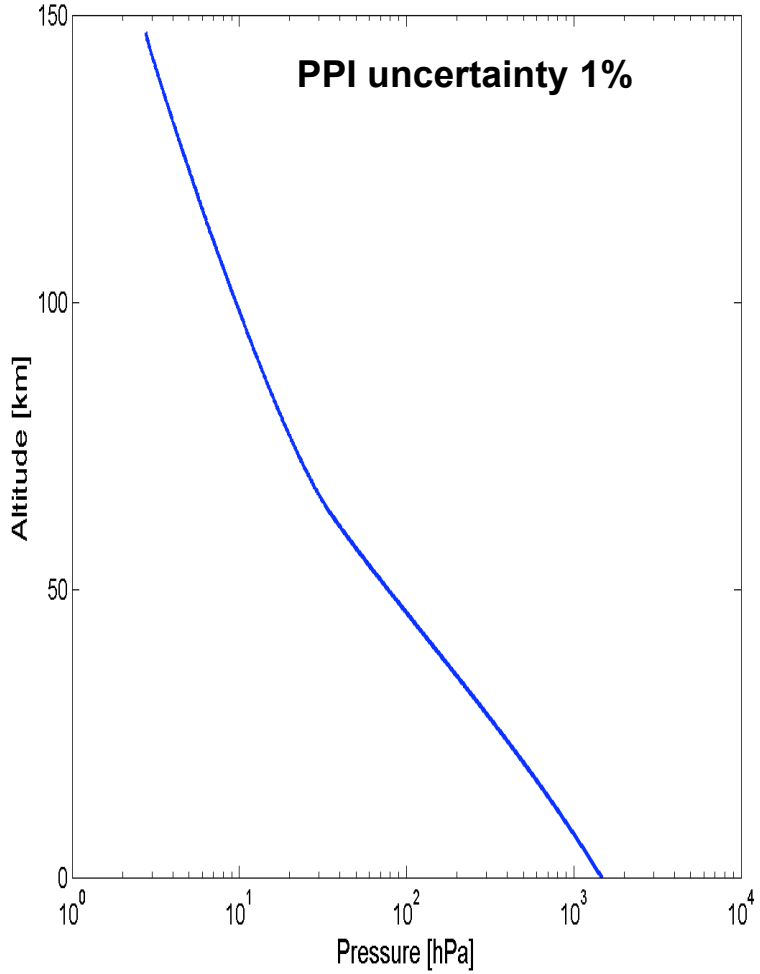
Main objective: to measure **Titan's atmospheric pressure**

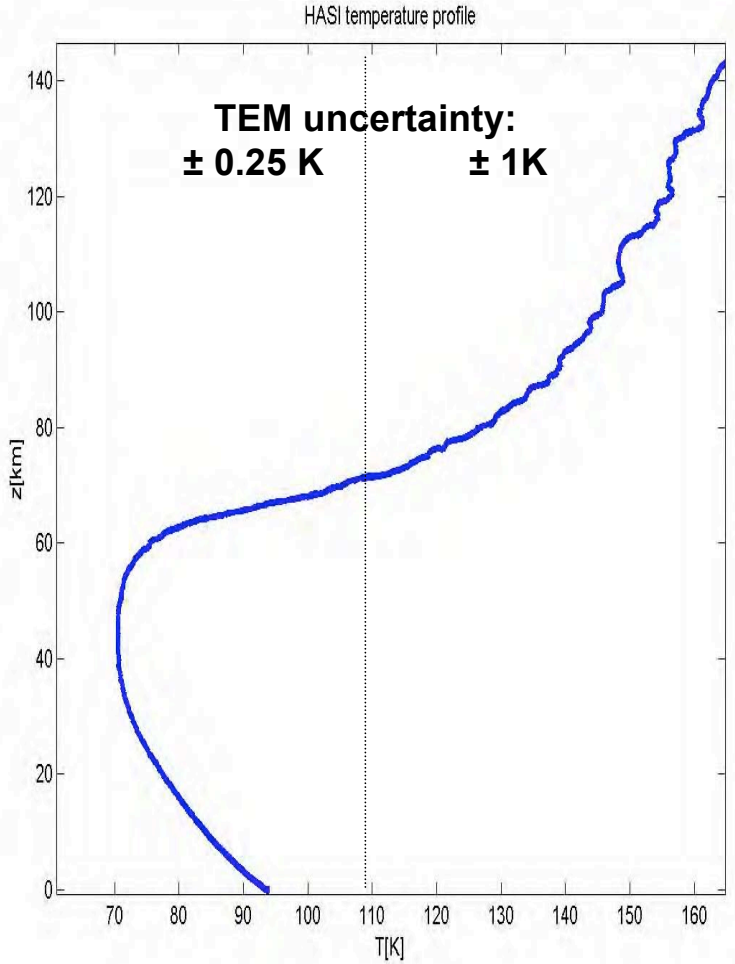
range	Resolution	Accuracy
Low (0-400 hPa)	0.01hPa	1%
Medium (0-1200 hPa)		
High (0-1600 hPa)		

HASI
Huygens Atmospheric Structure Instrument

HASI descent phase

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"





Credit: ESA / ASI / UPD / FMI

HASI
Huygens Atmospheric Structure Instrument

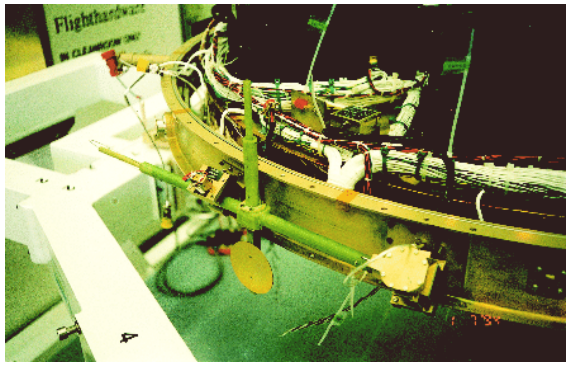
HASI Permettivity Wave & Altimetry

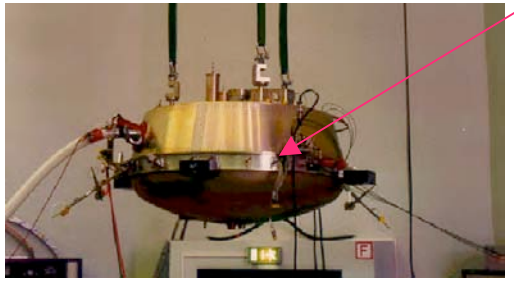
CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

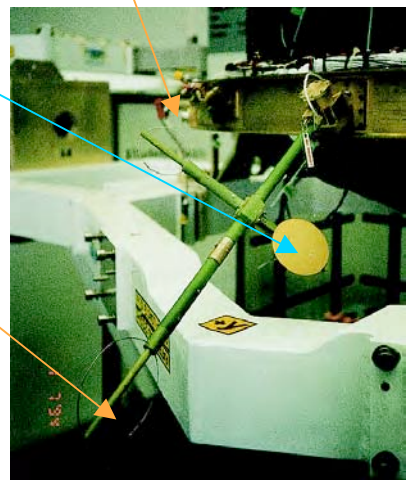
PWA sensors are 6 electrodes placed on two deployable booms

- a pair of **mutual impedance** transmitter (**TX**) and receiver (**RX**)
- a pair of **relaxation probes** (**RP**)

and an acoustic transducer (**ACU**)







HASI-PWA process also the **radar return signal** of the Huygens Proximity Sensor, deriving the spectrum and altitude information.

Main objective: to investigate **electrical properties** of Titan's atmosphere and surface

HASI
Huygens Atmospheric Structure Instrument

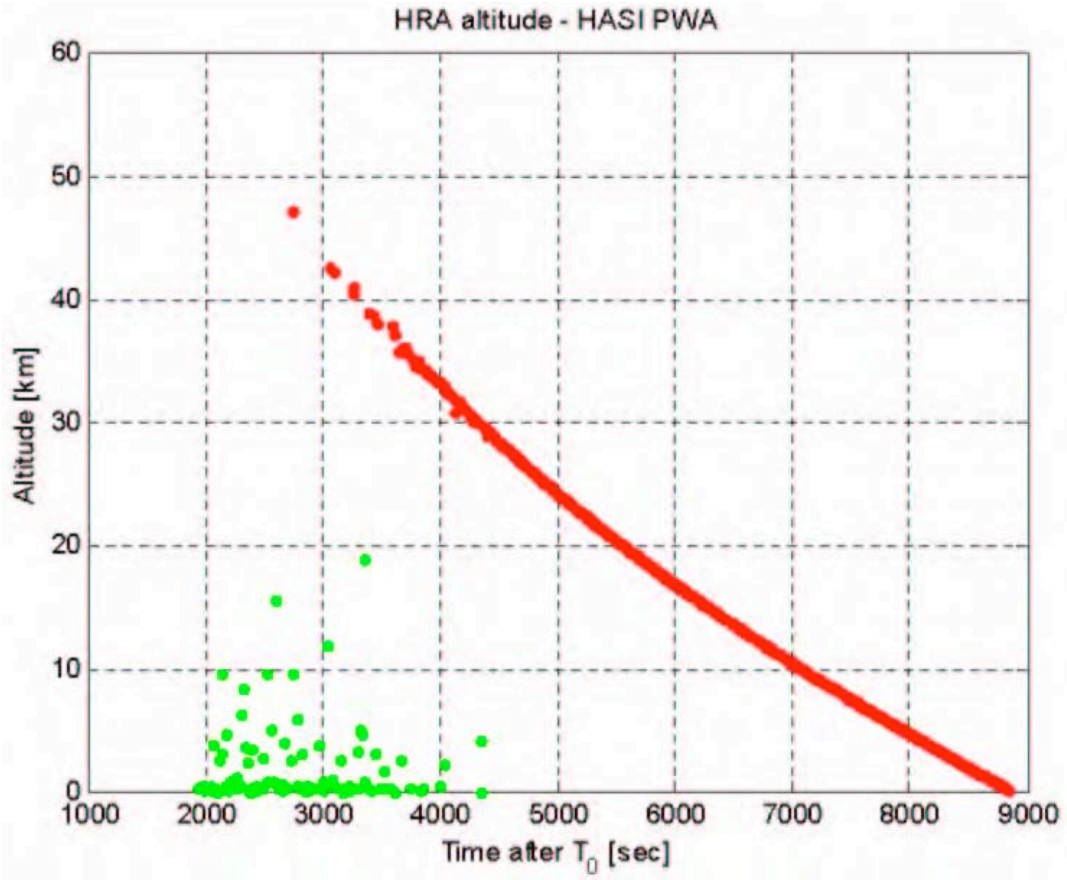
First HASI-PWA Radar data

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"

Probe altitude measured by the PWA sensor confirms radar lock starting at ~40 km

RADAR SOUNDTRACK:

"50 km down in 1 minute"



Credits: ESA / ASI / UPD / RSSD / IWF / CNRS / IAA

Impact Dynamics of Huygens

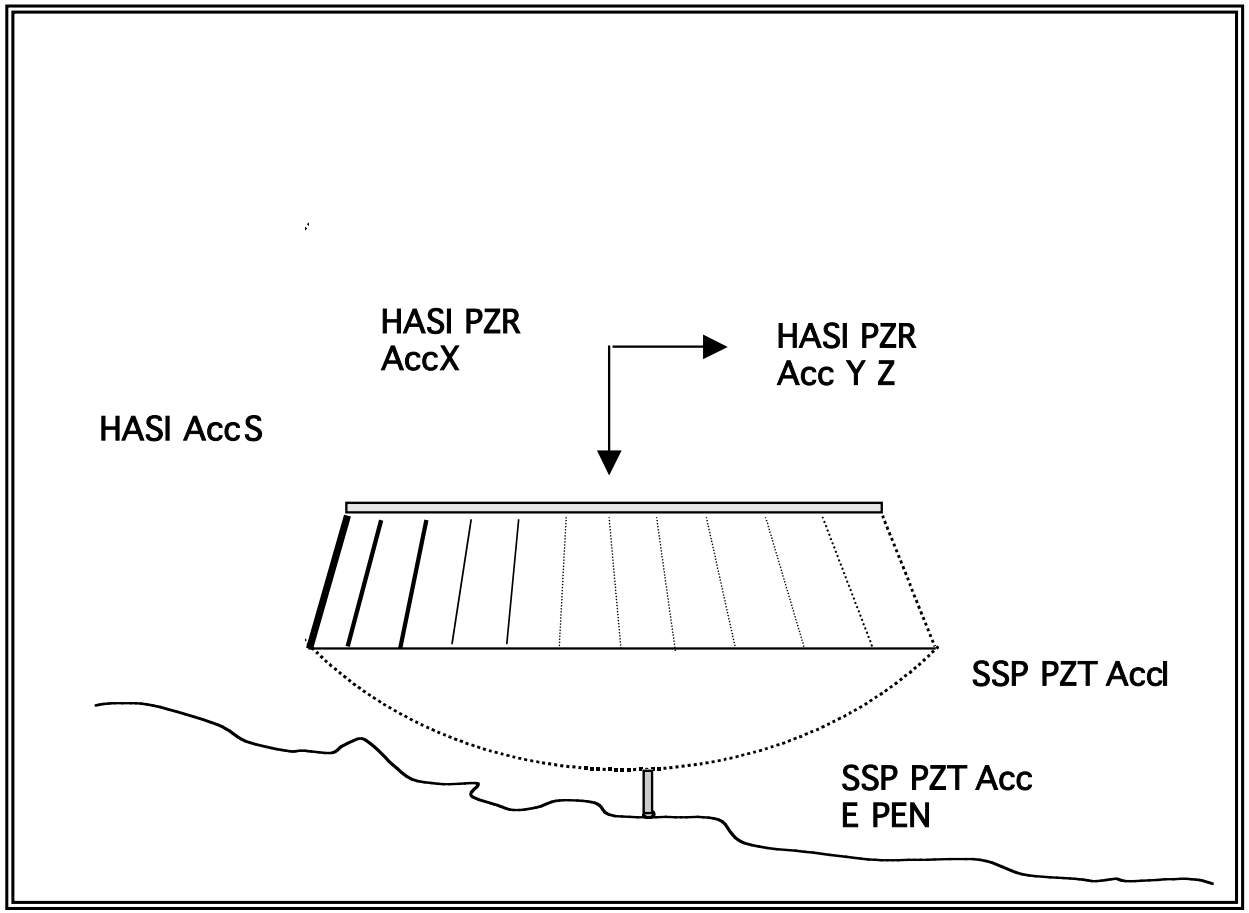
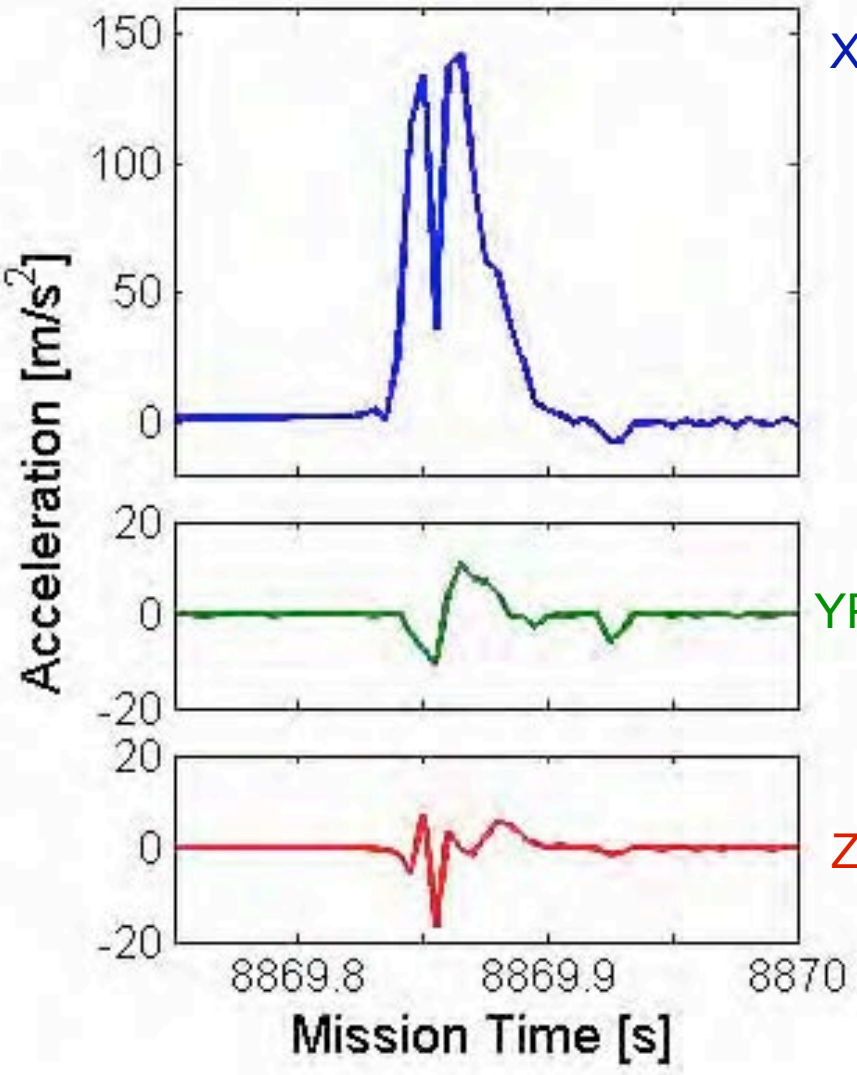


Figure 2. Accelerometer armada from HASI and SSP. Alignment with the spacecraft axis.

Tony McDonnell/OU

HASI ACC impact trace



XPZR

YPZR

ZPZR

Channels readouts :

3 axis ACC PZR for 6 s
@ 200Hz
(peak width 40 ms)

T_{impact} T0+2:27:49.840
(mission time)
= 11:38:10.587 UTC

Credit: ESA / ASI / UPD / OU

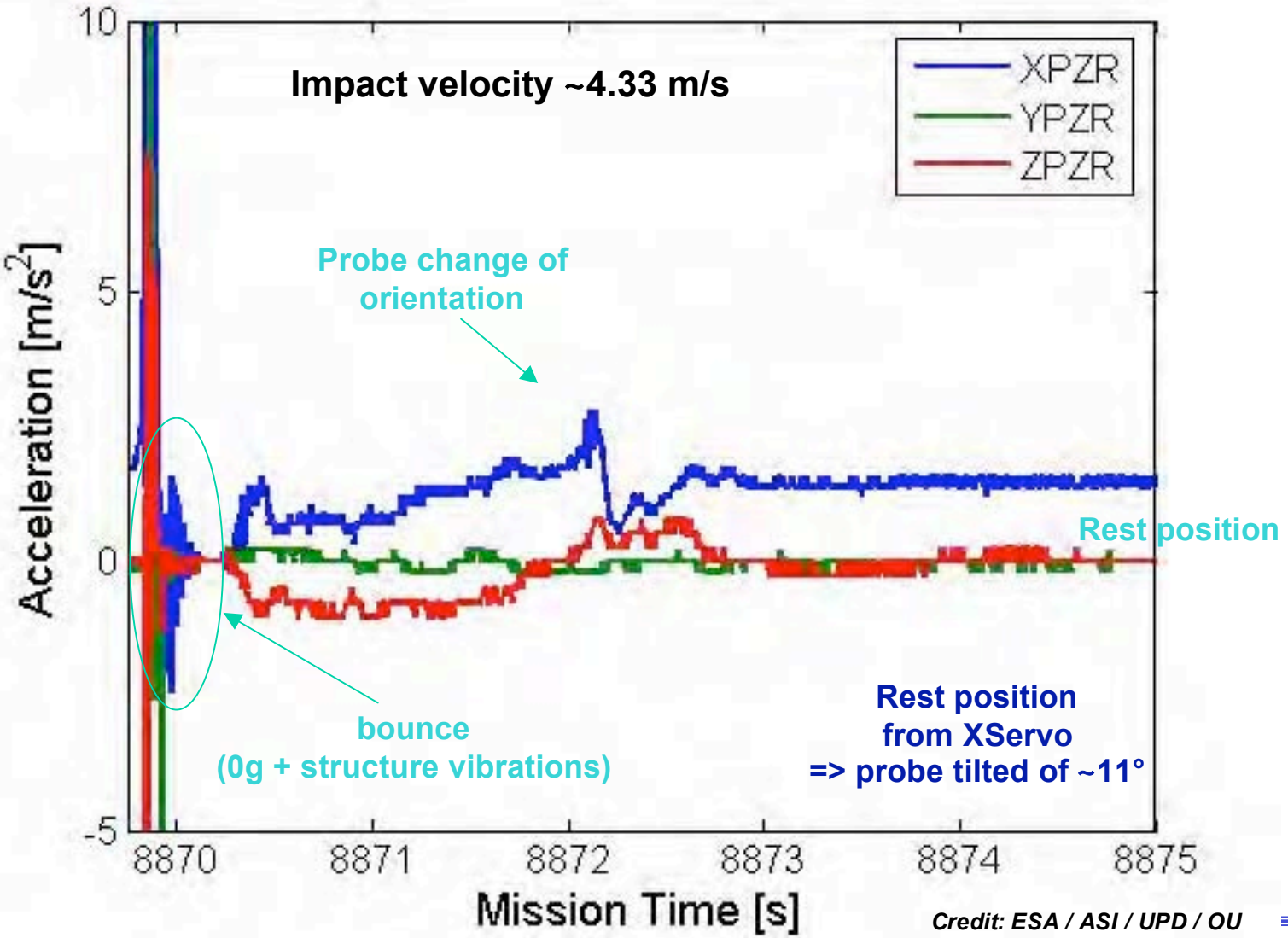
HASI ACC impact dynamics

- **Surface properties can be inferred from deceleration and bounce, tilt.**
- **Instantaneous impact angle, probe attitude can be deduced**
- **Impact velocity can be determined**
- **Repose position can also established**

HASI
Huygens Atmospheric Structure Instrument

HASI ACC impact trace

CISAS G.COLOMBO
Center of Studies and Activities for Space "G.Colombo"



Credit: ESA / ASI / UPD / OU

Surface phase

Meteo at surface:

- **Temperature 93.65±0.25 K**
- **Pressure 1467±1 hPa**